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SLOW-FLOW CO_2 LASER WITH CERAMIC TUBES

by

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EXPERIMENTAL INVESTIGATION OF DC EXCITATION SLOW-FLOW CO_2 LASER WITH CERAMIC TUBES

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Abstract: The laser output power of TEM_{00} mode from DC excitation slow-flow CO_2 laser made of ceramic tubes is 1.45 times higher as that of the laser made of glade of glass tubes. The experimental results are better than the distributed coated Au film catalyst used for improving output property of DC exciting slow-flow CO_2 laser by Mr. J. Macken. The mechanism of output power enhancement of the ceramic CO_2 laser was discussed.

KEY WORDS: laser made of ceramic tubes, gas temperature.

1. Introduction

Some new CO_2 lasers, such as radio frequency exciting large-area discharge waveguide CO_2 laser, Macken discharge CO_2 laser, etc., can provide very attractive output power. However, these devices suffer from difficulties in laser mode and structure, which can hardly be overcome.

As a medium to low power laser device, a direct current exciting slow-flow CO_2 laser has remained the most useful and simplest device to date. Comparatively focusing on the decomposition and composition of CO_2 gas, Macken, using a distributed gold-coated film, improved the output property of the DC exciting slow-flow CO_2 laser, and increased its power by 47%[1].

Nevertheless, experiment shows that the distributed gold-coated film catalyst technique is applicable only to larger discharge tubes with an inner diameter from 16mm to 28mm to provide output laser of the TEM^*_{01} mode . With this technique, the slow-flow device, while operating, must first excite the gold catalyst, and the method and parameters of excitation vary with the difference in the inner diameter of tubes and the mixing preparation ratio of laser gases.

During a laser experiment with the discharge tubes, specially coated with a gold film by Macken, the author found that the excitation of gold film turned out to be very difficult to realize. It is for this reason that a new approach to improve the output property of the DC exciting slow-flow CO_2 laser is proposed in this paper with a focus on the thermal effect of the device*.

2. Experiment and Result

The structure of the slow-flow CO_2 laser employed in this experiment is shown in Fig. 1. The optical resonant cavity of the device is a stable plano-concave cavity after primary deviation, which consists of output window, total reflection mirror and deviation reflector.

The ZnSe plane output window has transmittance 40%; the total

* The laser used in this paper is made of ceramic tubes without the necessity of applying catalyst.

reflection mirror is a germanium concave mirror with a curvature radius of 20m and reflectivity of 99%, while the deviation mirror is a silicon plane reflector with a reflectivity of 99%, which is placed closely in front of the total reflection mirror.

The laser wavelength is 10.6μm. The discharge plasma zone of the device is composed of two 1-m-long ceramic tubes in series; the ceramic tube contains 99.7% Al_2O_3 with an inner diameter of 7.8mm and wall thickness of 2mm.

The cylindrical non-oxygen copper anode and cathode, respectively, are located at two ends of the discharge zone. The optimal preparation ratio of CO_2 mixing gases is $CO_2:N_2:He=1:2.6:4.4$, and the prepositioned pressure of each of the three gases is $45x10^5$ Pa. The gases flow slowly, the pumping speed of the gas circulator is 0.71/s, and the optimal gas pressure of the device is $45x10^2$ Pa.

Externally, the ceramic tube is enclosed with a glassy cooling pipe, which is used to cool the device with deionized water. Two cavity mirror stands are also cooled through water; the water path is connected with the cooling water pipe in the discharge zone. The pumping speed of the circulator is 251/min; the water flow is in an opposite direction related to the gas flow. The temperature of the deionized water fluctuates between 12.7^0C and 15.5^0C. The deionized water in the circulating water tank is cooled with underground water.

The discharge current of the device is 70~72mA. The laser beam, emitted from the output window, passes through two total reflection deviation mirrors and throw itself onto an optical

shutter, the distance between the optical shutter and the output window being 2.2m.

The laser power meter is a Mode P-100 power meter manufactured by Laser-craft Inc. from the United States, which features 10s seconds of measurement time and a full scale power of 100W, while the thermometer is a 562 all-purpose digital thermometer developed in West Germany.

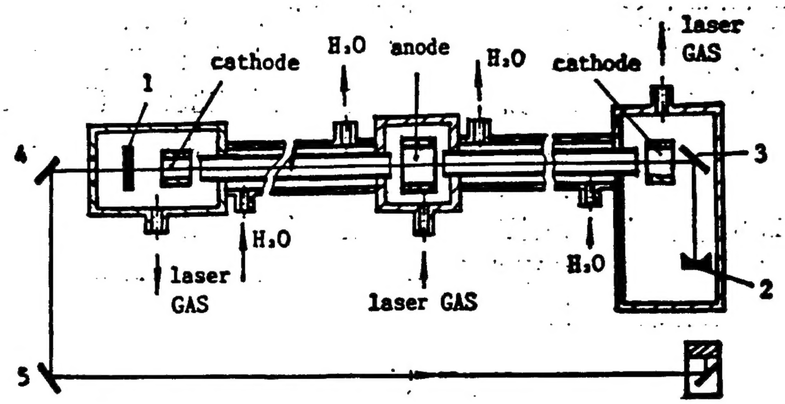

Fig. 1. Experimental configuration of DC exciting slow-flow CO_2 laser

Fig. 2. The laser mode of DC exciting slow-flow CO_2 laser with 2x1m ceramic tubes

TABLE 1

No.	1	2	3	4	5	6	7
[W]	175	172	171	174	173	180	175
[W]				174			

A comparison experiment was conducted using glass discharge tubes. These glass tubes, each 1-m-long with an inner diameter 8mm were connected in series to form a discharge zone as shown in Fig. 1. The outer wall of the tube is cooled with deionized water, and the structure and parameters of the optical resonant cavity as well as the external optical path system all stay unchanged.

The brand of glass is German Duran glass, and the gases flow slowly. The optimal gas preparation ratio of the glass tube is $CO_2:N_2:He=1:3:4$ (pressure ratio); the optimal gas pressure is $32.5x10^2$ Pa, and the optimal discharge current is 70mA.

With all the foregoing parameters, we measured the single mode output power of the ceramic tube laser as 174 W as shown in Table 1. The laser mode at the organic glass piece is shown in Fig. 2. It can be seen from Fig. 2 that the ceramic laser can output an ideal laser of TEM_{00} mode. The DC exciting slow-flow CO_2 laser can output 87W laser power of single mode at per m of discharge length, which is the best result ever derived. While in the comparison experiment, the glass tube laser output 120W laser power with the same TEM_{00} mode.

Noticeably, by comparing the output of the two devices, it is obvious that the TEM_{00} mode laser power derived from the ceramic tube laser was improved by 45% compared with that of the glass tube laser.

On the other hand, Macken, with a gold-coated catalyst, improved the TEM^{*}_{01} beam power of the slow-flow CO_2 laser by 47%. According to the optical resonant cavity theory, however, to improve the TEM_{00} mode power of the slow-flow CO_2 laser using the gold-coated catalyst, the fine ratio of its discharge tube is supposed to be much smaller than that of the TEM^{*}_{01} mode cavity tube. If so, the excitation of gold film will be made even more difficult, and the function of composing and regenerating CO_2 molecules will worsen. Therefore, for CO_2 lasers with single mode output, the ceramic tube is much more superior to Macken's gold-coated catalyst in terms of laser output power improvement.

3. Discussion

(1) Experiment shows that when the slow-flow laser made of ceramic tubes began to operate, its output power was almost the same as the glass tube laser in the comparison experiment. However, as the operation goes on, its output power slowly but steadily increased; this process lasted up to several hours.

This phenomenon can be interpreted as follows: Ceramic is a porous material, and when it is baked and stored in the air, its small holes will absorb large amounts of gases. When the laser device begins to operate, and the laser gases begin to discharge for excitation, the ceramic tube will be heated. The heated tube wall will release large amounts of absorbed gases, and when these gases enter the discharge space, they will greatly change the mixing gas preparation ratio of the device and its gas pressure to make them stay far away from the optimal value. In this case, the output power of the device is extremely low. However, as the

operating time of the device extended, the amount of gases released by the ceramic tube gradually reduces, and since the gases are constantly renewed while flowing slowly, they gradually reach their optimal preparation ratio and optimal gas pressure, resulting in a slow but steady increase in the power of the device. In fact, the device will not generate its maximum output power until the ceramic tube has completely released the absorbed gases.

To verify the foregoing analysis, we conducted an experiment, in which the wall of the tube was baked through discharge. In this experiment, the continuous discharge lasted 8h with a discharge current of 82mA. We measured the laser power in every hour of discharge when the current was lowered to the optimal value. The result showed that the laser power increased 7W on average in every hour of discharge baking. When the total discharge and baking operation was finished, the output power of the device reached up to 174W, namely 50W more than that at the beginning of the operation of the device.

Technically, for the ceramic tube, the best way is to put it in a vacuum furnace for degassing, and bring it to assembly process as soon as it is taken out of the furnace. The device should be kept in vacuum even when it is in idle condition.

(2) To further explore a mechanism, at which the power of ceramic tube laser can be significantly increased, we proceeded with an experiment as follows: We developed another two slow-flow CO_2 lasers, which were made of Al_2O_3 ceramic tubes with an inner diameter of 8mm and wall thickness of 2mm, and their discharge length, respectively, 1m and 1.5m. The optical resonant cavities of the two devices are stable plano-concave cavities with completely the same parameters. The transmittance of the ZnSe plane output window was 40%; the curvature radius of the total reflectance concave mirror was 20m with a reflectivity of 99%.

Also, we employed glass tubes in place of ceramic tubes for a comparison experiment. The glass tubes were, respectively, 1m and 1.5m long with an inner diameter of 8mm. The parameters of optical resonant cavities were kept unchanged during the experiment.

Fig. 3 and Fig. 4, respectively, show the experimental results of the four laser devices, which were derived before the ceramic tubes were totally baked and degassed.

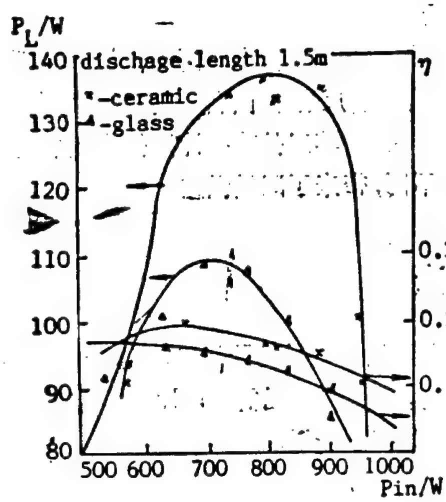

Fig. 3. Output laser power and O-E efficiency of DC exciting slow-flow CO_2 laser with ceramic tubes and glass tubes, respectively

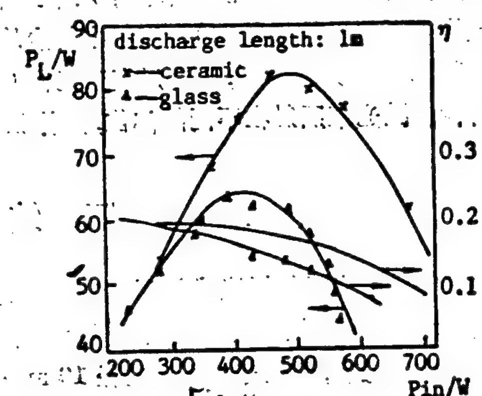

Fig 4

Fig. 4. Output power and efficiency of DC exciting slow-flow CO_2 laser with 1-m-long ceramic tube and glass tube, respectively

The input electric power which corresponds to the maximum output power point of the device is referred to as optimal input power. From Fig. 3, the optimal input power of the 1.5-m-long ceramic tube laser is 100W higher than that of the glass tube laser from the comparison experiment. From Fig. 4, the optimal input power of the 1-m-long ceramic tube laser is around 80W higher than that of the glass tube laser from the comparison experiment. In addition, both the output power and efficiency of the ceramic tube laser are higher than those of the glass tube laser.

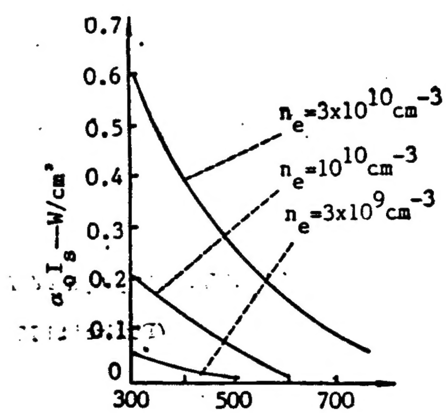

Fig. 5 Variation of maximum optical power density with electron density and gas temperature for CO_2-N_2-He (0.1-0.1-0.8) laser mixture at 10Torr

The output optical power density of the diffusion cooling CO_2 lasers (including slow-flow CO_2 laser and closed stationary CO_2 laser) depends on the electron concentration and gas temperature in the devices. The optical power density is proportional to the product of the small signal gain of the laser medium α_0 and saturation intensity I_s; the $\alpha_0 I_s$ rises with the increase in electron concentration, and declines with the increase in gas temperature as shown in Fig. 5[2].

In Figs. 3 and 4, we investigated a fixed input power point. At this point, the ceramic tube laser and glass tube laser share the same input electric power, yet the gas temperature of the ceramic tube laser is much lower than that of the glass tube laser. This is because the thermal conductivity coefficient of the ceramic tube containing 99.7% Al_2O_3 is 26W/mK, while the thermal conductivity coefficient of Duran glass is only 1.6W/mK. Again from Fig. 5, at the same input electric power, the ceramic tube laser will inevitably generate higher output power.

The electron concentration and gas temperature are also a pair of contradictory parameters. During the initial operation of the device, by enhancing the input electric power, the discharge current will go up, and as the electron concentration in laser plasma will increase, $\alpha_0 I_s$ will increase, followed by an increase in laser power. At this instance, the rise in gas temperature does not show a remarkable effect. However, with the continuous increase in input electric power, the gas temperature inside the device will accordingly increase significantly, which will gradually weaken the benefit brought by the increase in the electron concentration. In other words, with the increase in input electric power, the increase of laser power will gradually slow down. When the input electric power goes up to a specified point, the rise in gas temperature will entirely offset the benefit brought by the increase in electron concentration, and the net increase in $\alpha_0 I_s$ will be equal to

zero. While it is beyond this power point, the increased input electric power can only heat the gas, and the over-heated gas will lead to the decrease in $\alpha_0 I_s$; it is at this time that gas temperature will become a major restricting factor. Thus, this specified input power point can be thought of as the optimal input power.

From Fig. 4, the optimal input power of the 1-m-long glass tube laser is 410W, while in the case of the ceramic tube laser, due to its ideal thermal conductivity, the increase in input electric power can go on even after it has reached 410W, and the $\alpha_0 I_s$ will be still able to increase until the optimal input power point reaches approximately 490W. In this case, the laser power can arrive at its maximum value 82W, i.e., 18W more than that of the glass tube laser. Additionally, the output power of the 1.5-m-long ceramic tuba laser is 27W higher than that of the glass tube laser from the comparison experiment. Hence, it would not be difficult to comprehend that why the output power of the 2-m-long ceramic tube laser is 45% higher than that of the glass tube laser by contrast after thorough baking and degassing processes.

(3) The errors in laser power measurement originate from three sources. First, the reflectivity of the two deviation mirrors in the external optical path system can directly affect the measurement results (Fig. 1), and the dust in the air can blur the mirror surface and reduce its reflectivity. Second, there are errors in measurement time. Normally, 10s are manually controlled, but human reaction takes 0.5 to 1s. Third, there is inhomogeneity at the blackbody surface of the power meter. Since the laser beam irradiates different sections, the blackbody has different absorptance, which will give rise to measurement errors.

4. Conclusions

An experiment with a slow-flow CO_2 laser made of ceramic tubes was described in this paper. Through baking and degassing, this laser generated TEM_{00} mode beam output power 87W per each m of discharge length, i.e., 45% more than a glass tube laser could achieve. This laser, without requiring Macken's distributed gold-coated catalyst and excitation treatment, is applicable for single mode lasers with an inner diameter of a discharge tube below 16 mm.

The foregoing experiment was completed in Carl Baasel Laser Technology Inc. in Republic Germany. The author hereby expresses his genuine acknowledgement to Helmt Paul for his assistance regarding the device structure, and to Dr. L. Langhans for his constructive discussion of this experiment.

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